NACA

RESEARCH MEMORANDUM

THE EFFECT OF BLUNT-TRAILING-EDGE ELEVONS ON THE

LONGITUDINAL AND LATERAL HANDLING QUALITIES

OF THE X-4 SEMITAILLESS AIRPLANE

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SUMMARY

A flight program has been in progress with the Northrop X-4 semi-
tailless airplane to investigate the effect on the longitudinal and
lateral stability and control of thickened elevons having trailing-edge
thickness one-half the control-hinge-station thickness. The investi-
gation consisted of speed runs, wind-up turns, abrupt rudder-fixed rolls,
and longitudinal pulses between Mach numbers of 0.63 and 0.94 at pressure
altitudes near 30,000 feet.

By comparing the results with similar data for the original X-4
with conventional elevon trailing edges, it was found that the longi-
tudinal control deflection necessary to maintain level flight was
reduced 20 percent at a Mach number of 0.64 and 60 percent at a Mach
number of 0.84 by the thickened elevon configuration. The modified
configuration experienced only small and relatively minor trim changes
until a nose-down change was encountered at an approximate Mach number
of 0.91; whereas the original configuration experienced several large
trim changes at Mach numbers between 0.74 and about 0.90. The normal-
force coefficient—Mach number boundary for the decrease of static
longitudinal stability was affected little by thickening the elevons.
The longitudinal control effectiveness of the modified airplane increased
above a Mach number of 0.85 and decreased rapidly beyond a Mach number of
about 0.90; however, at approximately 0.92 the effectiveness is as great
as at the lowest test speeds. For the original airplane the control
effectiveness decreased rapidly beyond a Mach number of approximately
0.87. Although the Mach number range of the X-4 airplane was extended
because of this improvement in control effectiveness at high Mach num-
bers, the safe Mach number range was limited to about 0.92 by initiation
of a high-frequency longitudinal oscillation, which increased to danger-
ous amplitudes (±1.5g) as Mach number was increased to approximately 0.94
(as permitted by the modification). The initial low-amplitude oscilla-
tion occurred at the same Mach number for both original and modified
configurations.

The lateral control was significantly improved by the thickened elevons. The attainable helix angle per degree aileron was increased by 40 to 85 percent throughout the Mach number range, and the time to roll to 90° was reduced between 15 and 25 percent.

INTRODUCTION

The swept-wing Northrop X-4 airplane was constructed to obtain stability and control information at transonic Mach numbers on an airplane having no horizontal tail. Flight tests indicated that, among other difficulties, the airplane suffered severe reductions in longitudinal and lateral control near $M \approx 0.88$ (ref. 1). A control effectiveness investigation (ref. 2) revealed that lateral control for a comparable wing was significantly improved through reduction of the trailing-edge angle by blunting the trailing edge. It was decided, therefore, to fit the X-4 with similarly modified control surfaces to determine whether flight results would reflect improvements consistent with reference 2 and whether the modification would influence the longitudinal stability characteristics of the airplane.

The investigation which followed covered the transonic Mach number range to $M \approx 0.94$ and consisted of speed runs, wind-up turns, abrupt rudder-fixed rolls, and longitudinal pulses at pressure altitudes near 30,000 feet. The results of the investigation are presented in this paper and are compared with the results for the original configuration.

SYMBOLS

A_Z	normal acceleration, g units
b	wing span, ft
$\bar{c}$	wing mean aerodynamic chord, M.A.C., ft
C_m	pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qS\bar{c}}$
C_{N_A}	airplane normal-force coefficient WA_Z/qS
$dC_m/d\alpha$	rate of change of pitching-moment coefficient with angle of attack, per deg, static stability parameter
$dC_{N_A}/d\alpha$	normal-force-curve slope, per deg
$d\delta_e/dC_{N_A}$	apparent static stability parameter, deg

g	acceleration due to gravity, ft/sec^2
h_p	pressure altitude, ft
h	thickness of elevon at hinge-line station, percent chord
M	Mach number
p	rolling velocity, radians/sec
P	ambient pressure, lb/sq ft
$pb/2V$	wing-tip helix angle, radians
q	dynamic pressure, $0.7M^2P$, lb/sq ft
S	wing area, sq ft
t	time, sec
$T_{\phi=90^\circ}$	time to roll to 90° bank angle, sec
V	true velocity, ft/sec
W	airplane weight, lb
α	angle of attack, deg
β	angle of sideslip, deg
δ_a	effective lateral control angle, $\delta_{e_L} - \delta_{e_R}$, deg
δ_e	effective longitudinal control angle, $\dfrac{\delta_{e_L} + \delta_{e_R}}{2}$, deg
$\dot{\theta}$	pitching velocity, radians/sec
φ	angle of bank, deg

Subscripts:

max	maximum
L	left
R	right

AIRPLANE AND INSTRUMENTATION

The general physical characteristics of the X-4 airplane are given in table I. A three-view drawing is shown in figure 1 and photographs of the airplane and the modification appear in figures 2 and 3, respectively. Figure 4 shows a profile sketch of the modified elevon.

The elevons were modified by cementing balsa wood fillers to the upper and lower surfaces so as to provide straight sided profiles having a trailing-edge thickness of one-half the hinge-station thickness. The surfaces were sanded and lacquered to a smooth finish. This modification reduced the trailing-edge angle from approximately 19° to 8°.

The quantities pertinent to this study were recorded by standard NACA instrumentation synchronized by a common timer.

TESTS AND METHODS

The longitudinal data presented in this paper were obtained from speed runs, longitudinal pulses, and wind-up turns, that is, turns in which g is gradually increased while speed is held as nearly constant as possible. The lateral data were obtained from abrupt rudder fixed rolls. All maneuvers were performed between Mach numbers of 0.63 and 0.94 at pressure altitudes of approximately 30,000 feet. Reynolds number varied between 12×10^6 and 25×10^6, based on the mean aerodynamic chord. The airplane center of gravity varied between 17 and 18 percent M.A.C.

The airspeed calibration used for the present investigation was determined by the method of reference 3. The values of $dC_m/d\alpha$ were obtained, as in reference 4, by using the period and damping of the airplane following longitudinal pulses.

RESULTS AND DISCUSSION

Longitudinal Stability and Control

The variation of trim δ_e with M for level flight is shown in figure 5. For the thickened elevon configuration the variation of δ_e with M is stable and nearly linear to $M \approx 0.91$ except for a neutrally stable region between $M = 0.84$ and $M = 0.87$. As Mach number is increased above 0.91, a nose-down trim change is experienced, which continues to $M \approx 0.94$, the limit of the investigation. For the original configuration the longitudinal control deflection necessary for level flight is from 1° to more than 2° greater than for the modified configuration for essentially the same center-of-gravity location. For the original configuration several trim changes occurred. The most

pronounced of these were nose-down trim changes occurring at $M \approx 0.74$, 0.85, and 0.90 and a nose-up trim change at $M \approx 0.88$. Modification of the elevons eliminated the trim change at $M \approx 0.74$ and caused the trim changes at the other Mach numbers to be much less severe.

In reference 1 it is reported that the original configuration encountered a region of stability decrease (pitch-up) as moderately high normal-force coefficients were reached. Time histories of three representative turns for the modified configuration appear in figure 6. Figure 7, cross-plotted data from figure 6, shows that at moderate lift values the variation of δ_e with α is linear; however, as lift is increased, this curve breaks ($d\delta_e/d\alpha$ becomes less positive) and reference to the corresponding time history indicates accompanying relatively high pitching velocities. The occurrence of the break in the curve of δ_e against α with the relatively high values of $\dot{\theta}$ establishes the point of decreasing stability. The points chosen from the three representative plots are indicated by flagged symbols in figure 7 where it can be seen that the stability decrease occurs near stall. The relationship of δ_e and α following the point of stability decrease does not represent the true airplane stability when excessive pitching acceleration is encountered. Pilot comments state that flight beyond the chosen stability decrease points is objectionable.

The values of α and C_{N_A} at which the decrease in stability occurred were taken from figures 6 and 7 and are plotted as functions of M in figure 8 along with similar data for the original configuration from reference 1. As can be seen, the modified elevon configuration increases the stability decrease boundary only slightly over that of the original configuration $\left(\text{fig. 8, } C_{N_A} \text{ and } M \text{ relationship}\right)$; however, because this boundary is near $C_{N_{A_{max}}}$ (ref. 5) where a large change in α results in a relatively small change in C_{N_A}, the modified elevon provides an advantage in angle of attack of 2° to 5° in the stability decrease boundary relating α and M. The $C_{N_{A_{max}}}$ boundary and the objectionable buffet boundary of the original configuration are shown in figure 8. Insufficient data were available to determine $C_{N_{A_{max}}}$ for the modified configuration.

The variations of $dC_m/d\alpha$ and $d\delta_e/dC_{N_A}$ with Mach number are shown in figures 9 and 10, respectively. Since the values and the variation of $dC_m/d\alpha$ with M are similar for both configurations, indicating the modification had no effect on the low-lift stability of the airplane, the curves of $d\delta_e/dC_{N_A}$ plotted against M are representative of the elevon

effectiveness for the two configurations up to $M \approx 0.92$, which is the highest M value for which $dC_m/d\alpha$ is known. Beyond $M \approx 0.92$ a portion of the apparent control loss may be a result of an increase in stability. The modified elevon data indicate an increase of control effectiveness between $M \approx 0.84$ and 0.89 and a sudden decrease beyond $M \approx 0.90$; however, at M values immediately below 0.92 the control effectiveness appears to be as great as at the lowest test speeds. The original configuration suffers rapid longitudinal-control loss as M is increased beyond 0.87. As a consequence of this loss of control for the original configuration, the unmodified airplane was limited to $M \approx 0.92$, whereas $M \approx 0.94$ has been reached by the modified airplane.

The variation of the normal-force-coefficient slope with Mach number is shown in figure 11. The value of $dC_{N_A}/d\alpha$ for the modified elevon configuration increases gradually from about 0.04 to 0.07 as M is increased from 0.65 to 0.85. Beyond $M \approx 0.85$ there are insufficient data to establish an accurate faired variation of $dC_{N_A}/d\alpha$ with M; however it appears that $dC_{N_A}/d\alpha$ increases rapidly with increasing M. In comparison $dC_{N_A}/d\alpha$ for the original configuration is at least 0.01 greater over the Mach number range where the configurations can be compared.

The X-4 airplane, original or modified, has on four occasions encountered longitudinal oscillations of about 2 cps at high Mach numbers. One of these oscillations of low amplitude, obtained with the original airplane, is discussed in reference 1. Three oscillations of this frequency have been encountered with the modified airplane and two of these have reached dangerous amplitudes, approximately ± 1.5g, (figs. 12(a) and 12 (b)). These oscillations are shown because they illustrate the dangerous characteristics of the airplane for these conditions $\left(C_{N_A} \approx 0.2, \quad M \approx 0.94\right)$. The airplane-induced oscillation shown in figure 12(a) increased steadily in amplitude from about ± 0.3g to approximately ± 1.6g. The amplitude continued to increase for 3 cycles beyond the reduction in the longitudinal control deflection and the rapid reduction in Mach number was the factor which finally induced damping. The pilot-induced oscillation of figure 12(b), of the same frequency, was initiated by an elevon motion of $\pm 2^{\circ}$ at a frequency of about $1\frac{1}{2}$ cycles per second. The oscillation continued with little damping for 10 cycles, finally reaching ± 1.5g. The relationship between pitching velocity and rate of roll suggests lateral coupling in this case. The two oscillations of this same frequency, but of much lower amplitude, about ± 0.3g, were encountered at $M \approx 0.92$ and $C_{N_A} \approx 0.2$. Although the modified X-4 has reached $M \approx 0.94$, the safe limit for this configuration is considered to be $M \approx 0.92$, where the ± 0.3g oscillations are encountered. While the high amplitude oscillations are not the direct result of thickening the elevons, the delay in loss of longitudinal

control furnished by the modification extended the Mach number range to a point where dangerous amplitudes were reached.

The region of occurrence for these four oscillations (2 cps) is shown in figure 13. Figure 13 also shows the complete usable C_{N_A},M envelope of the X-4; and in addition this figure illustrates that although the loss in longitudinal control has been delayed by the thickened elevons, the initial Mach number for occurrence of the 2-cps low-amplitude oscillation, $M \approx 0.92$, remains as the limiting factor in the usable C_{N_A},M envelope. The divergent oscillation about all three axes shown in this figure occurred twice for the original configuration and was considered to be a factor limiting the M range, reference 1. Because of its infrequent occurrence and because of the limited experience with the thickened elevon configuration, it is not known whether this oscillation remains as a limiting factor for the modified airplane.

Lateral Control

Lateral control characteristics have been determined for one-half deflection, rudder-fixed aileron rolls at pressure altitudes near 30,000 feet. The effect of thickened elevons on lateral control is shown in figure 14. At a Mach number of 0.64, the time to roll to 90° is reduced from 1.1 to 0.9 seconds by thickening the elevons and at $M \approx 0.86$, $T_{\phi=90^\circ}$ is reduced from 0.9 to 0.7 second so that a 15- to 25-percent reduction in $T_{\phi=90^\circ}$ is realized throughout the Mach number range covered. The value of $T_{\phi=90^\circ}$ increased sharply beyond $M = 0.89$ for the modified configuration, but the data were not available to determine the Mach number at which $T_{\phi=90^\circ}$ increased for the original configuration.

Shown in figure 14(b) is the variation of $\frac{pb/2V}{\delta_a}$ with Mach number. The values of $\frac{pb/2V}{\delta_a}$ for the modified configuration are about 40 percent greater than for the normal configuration at $M \approx 0.64$ and approximately 85 percent greater at $M \approx 0.88$. The lateral control decreases rapidly beyond $M \approx 0.89$ for the modified configuration. In general, the flight data confirm the findings of reference 2 regarding the effect of thickened trailing edges on lateral control.

CONCLUSIONS

The effects of thickening the elevon trailing edges on the X-4 airplane to one-half the hinge-station thickness were found to be as follows:

1. Longitudinal control deflection required for level flight was reduced 20 percent at a Mach number of 0.64 and 60 percent at a Mach number of 0.84 by the thickened elevon configuration. The modified configuration experienced no abrupt trim changes until a gradual nose-down change occurred at Mach number of approximately 0.91. The original configuration experienced nose-down changes at Mach numbers of 0.74, 0.85, and 0.90 with a nose-up change occurring at a Mach number of approximately 0.88.

2. The normal-force coefficient—Mach number boundary defining the region of decreasing static longitudinal stability was little affected by thickening the elevons.

3. The longitudinal control effectiveness of the modified airplane increased above a Mach number of 0.85 and decreased rapidly beyond a Mach number of about 0.90, however at approximately 0.92 the effectiveness is still as great as at the lowest test Mach numbers. For the original airplane the control effectiveness decreases rapidly beyond a Mach number of about 0.87.

4. The safe Mach number range of the X-4 was considered limited to a Mach number of 0.92, normal-force coefficient approximately 0.2, by the initiation of a longitudinal oscillation which increased to a dangerous amplitude if Mach number was increased (as permitted by the modification). The initial low-amplitude oscillation occurred at the same Mach number for both the original and modified configurations.

5. The attainable helix angle per degree aileron was increased by 40 to 85 percent throughout the Mach number range by the thickened control surfaces and the time to roll to 90° was reduced 15 to 25 percent.

High-Speed Flight Station,
　　National Advisory Committee for Aeronautics,
　　　　Edwards, Calif., October 18, 1954.

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2. Strauss, H. Kurt, and Fields, Edison M.: Flight Investigation of the Effect of Thickening the Aileron Trailing Edge on Control Effectiveness for Sweptback Tapered Wings Having Sharp- and Round-Nose Sections. NACA RM L9L19, 1950.

3. Zalovcik, John A.: A Radar Method of Calibrating Airspeed Installations on Airplanes in Maneuvers at High Altitudes and at Transonic and Supersonic Speeds. NACA Rep. 985, 1950. (Supersedes NACA TN 1979.)

4. Holleman, Euclid C., Evans, John H., and Triplett, William C.: Preliminary Flight Measurements of the Dynamic Longitudinal Stability Characteristics of the Convair XF-92A Delta-Wing Airplane. NACA RM L53E14, 1953.

5. Baker, Thomas F.: Results of Measurements of Maximum Lift and Buffeting Intensities Obtained During Flight Investigation of the Northrop X-4 Research Airplane. NACA RM L53G06, 1953.

TABLE I.- PHYSICAL CHARACTERISTICS OF NORTHROP X-4 AIRPLANE

Airplane:
  Weight, lb
    Maximum 7,820
    Minimum 6,450
  Engines (two) . . . . Westinghouse J-30-WE-7-9
    Rating (each), static thrust at sea level, lb 1,600
  Center-of-gravity travel, percent M.A.C.:
    Gear up, full load 18.3
    Gear up, post flight 16.3

Wing loading, lb/sq ft:
  Maximum 39.1
  Minimum 32.2

Wing:
  Area, sq ft 200
  Span, ft 26.8
  Airfoil section (exclusive of elevon, see fig. 4) . . . . NACA 0010-64
  Mean aerodynamic chord, ft 7.81
  Aspect ratio 3.6
  Root chord, ft 10.25
  Tip chord, ft 4.67
  Sweepback (leading edge), deg 41.57
  Dihedral (chord plane), deg 0

Wing boundary-layer fences:
  Length, percent local chord 30.0
  Height, percent local chord 5.0
  Location, percent semispan 90.0

Elevons:
  Area (total), sq ft 17.20
  Chord, percent wing chord 20
  Profile . . . . See figure 4
  Movement, deg:
    Up 35
    Down 20
  Operation . . . . Hydraulic with electrical emergency

Vertical tail:
  Area, sq ft 16
  Height, ft 5.96

Rudder:
  Area, sq ft 4.1
  Span, ft 4.3
  Travel, deg . . . . ±30
  Operation . . . . Direct
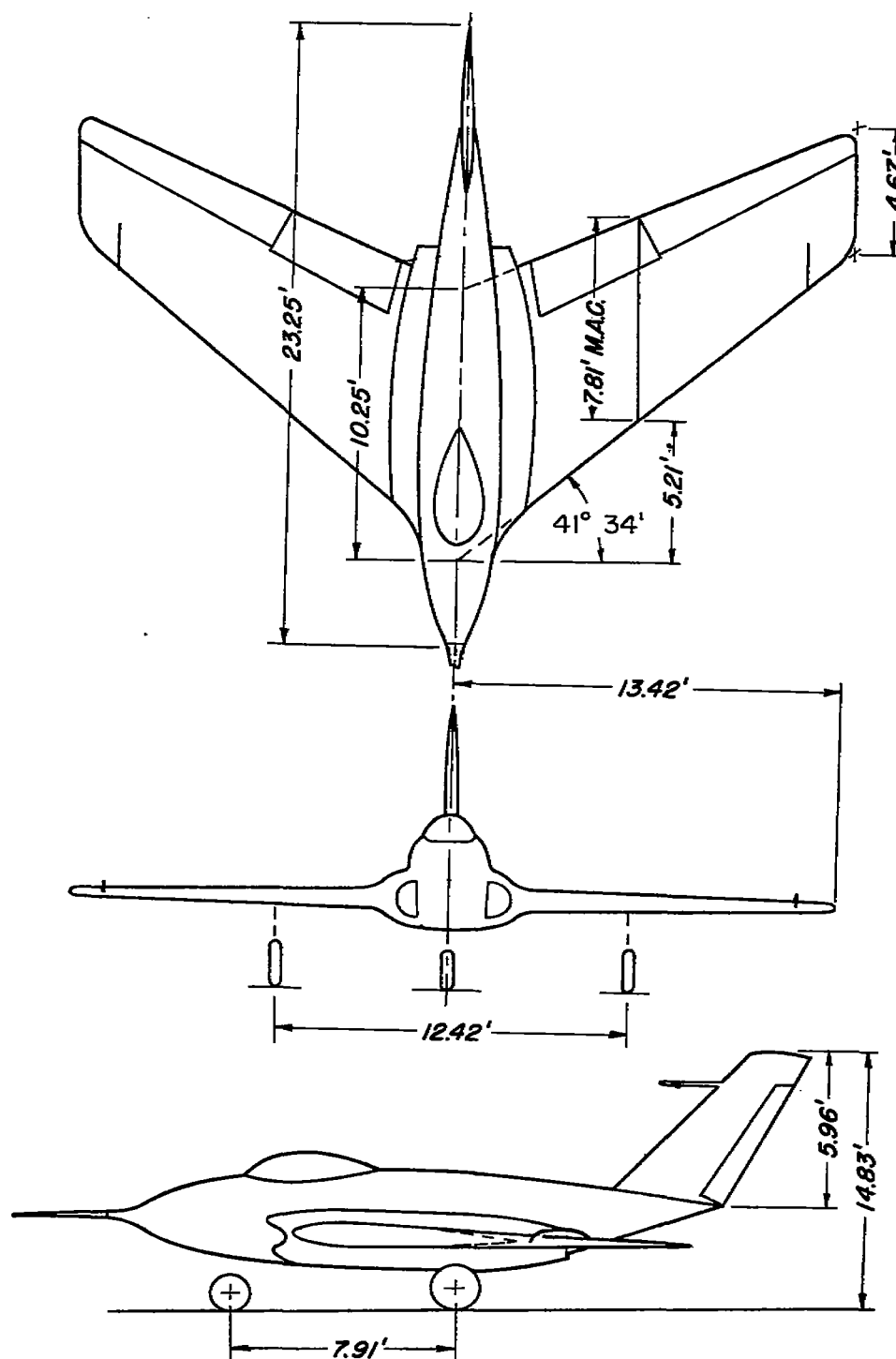
Figure 1.- Three-view drawing of the Northrop X-4 airplane.
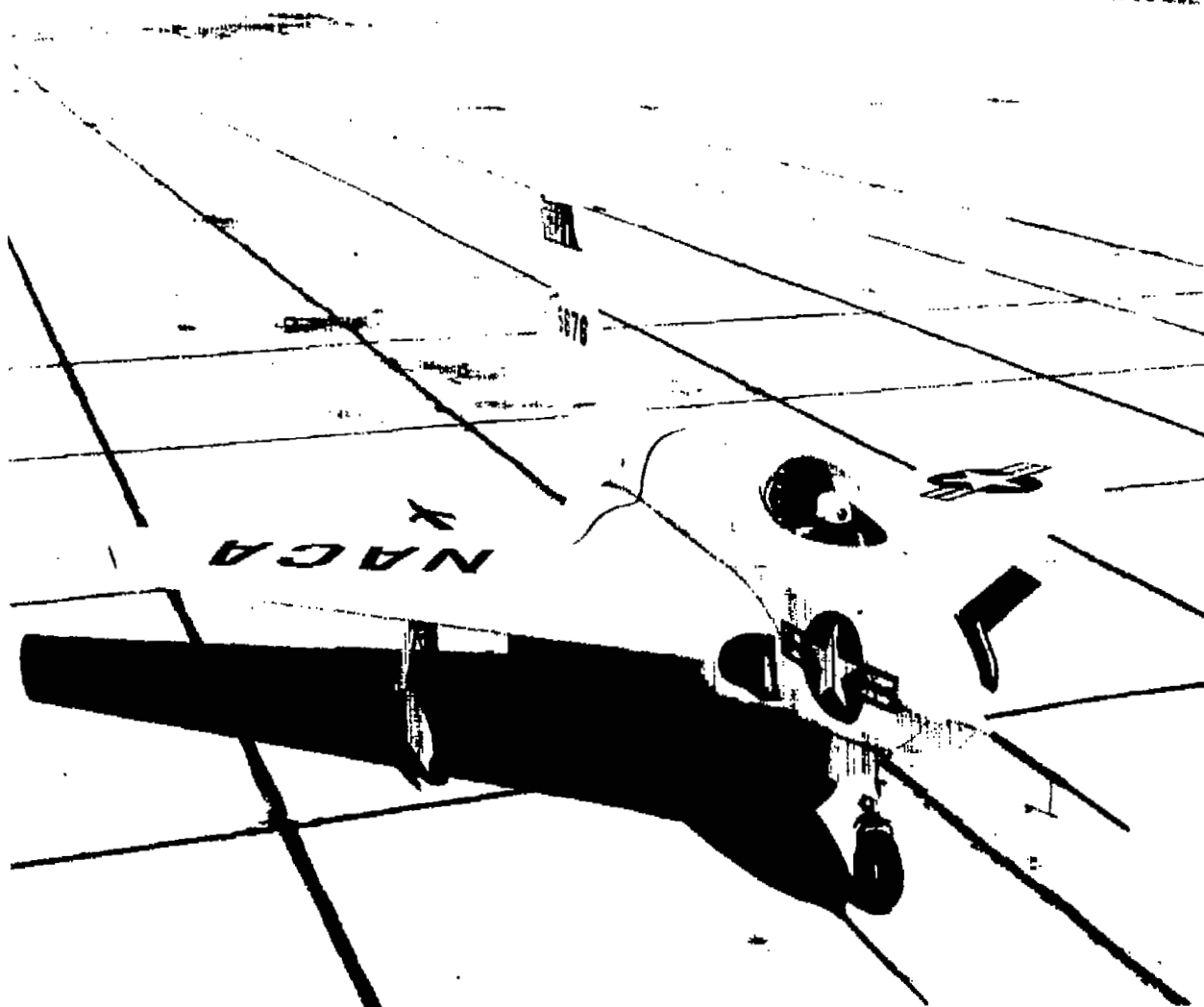
L-86441

Figure 2.- Photograph of X-4 semitailless airplane.
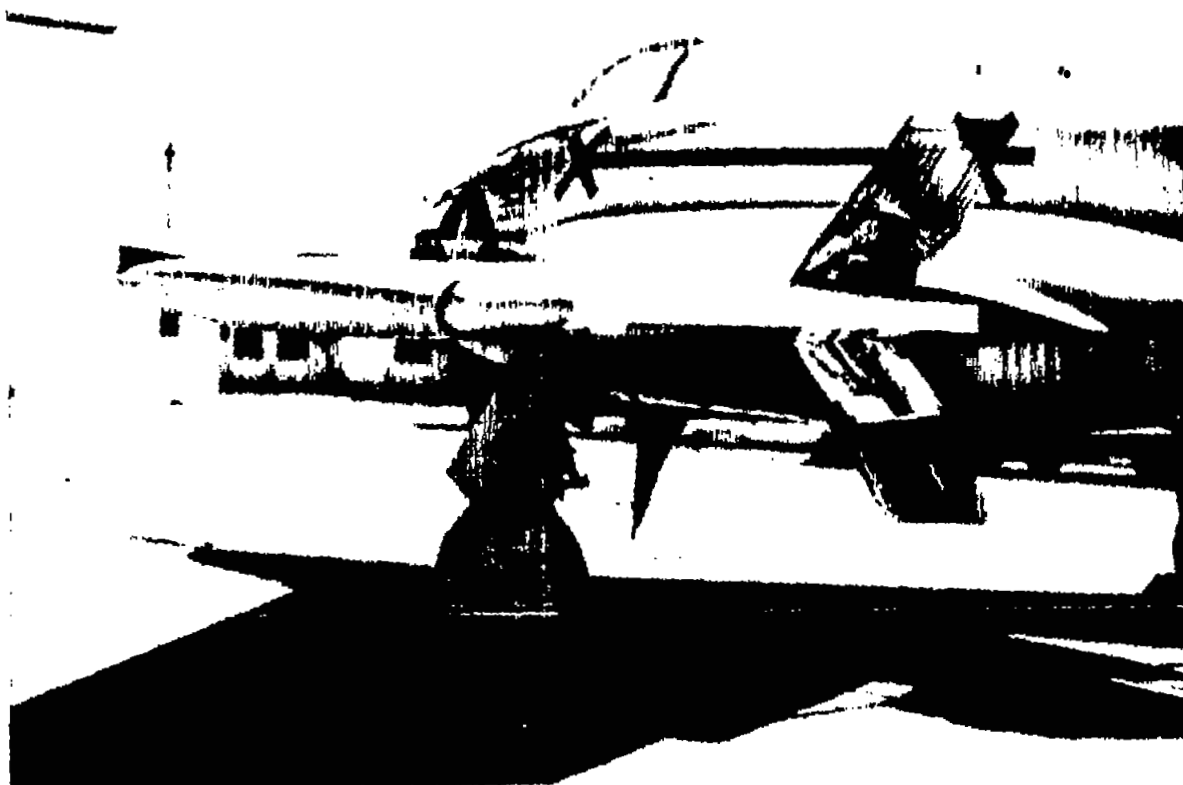
I-86442

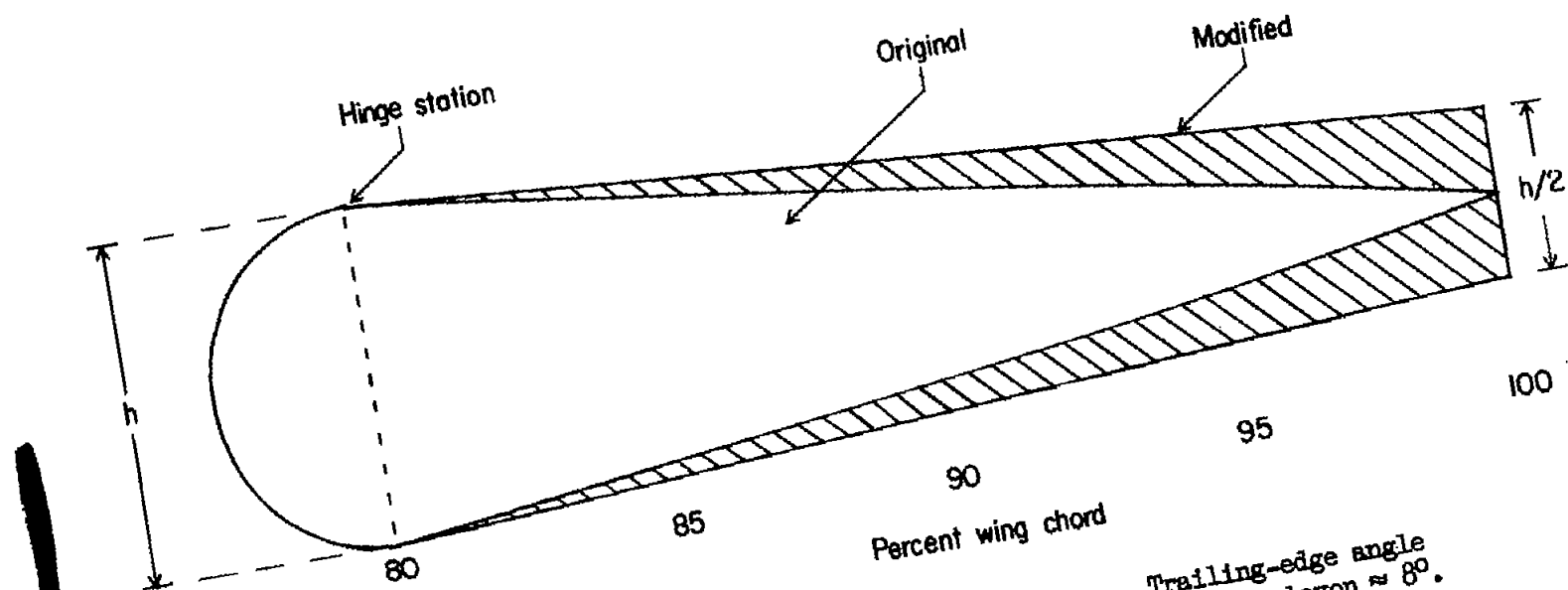Figure 3.- Photograph of modified elevons of X-4 semitailless airplane.

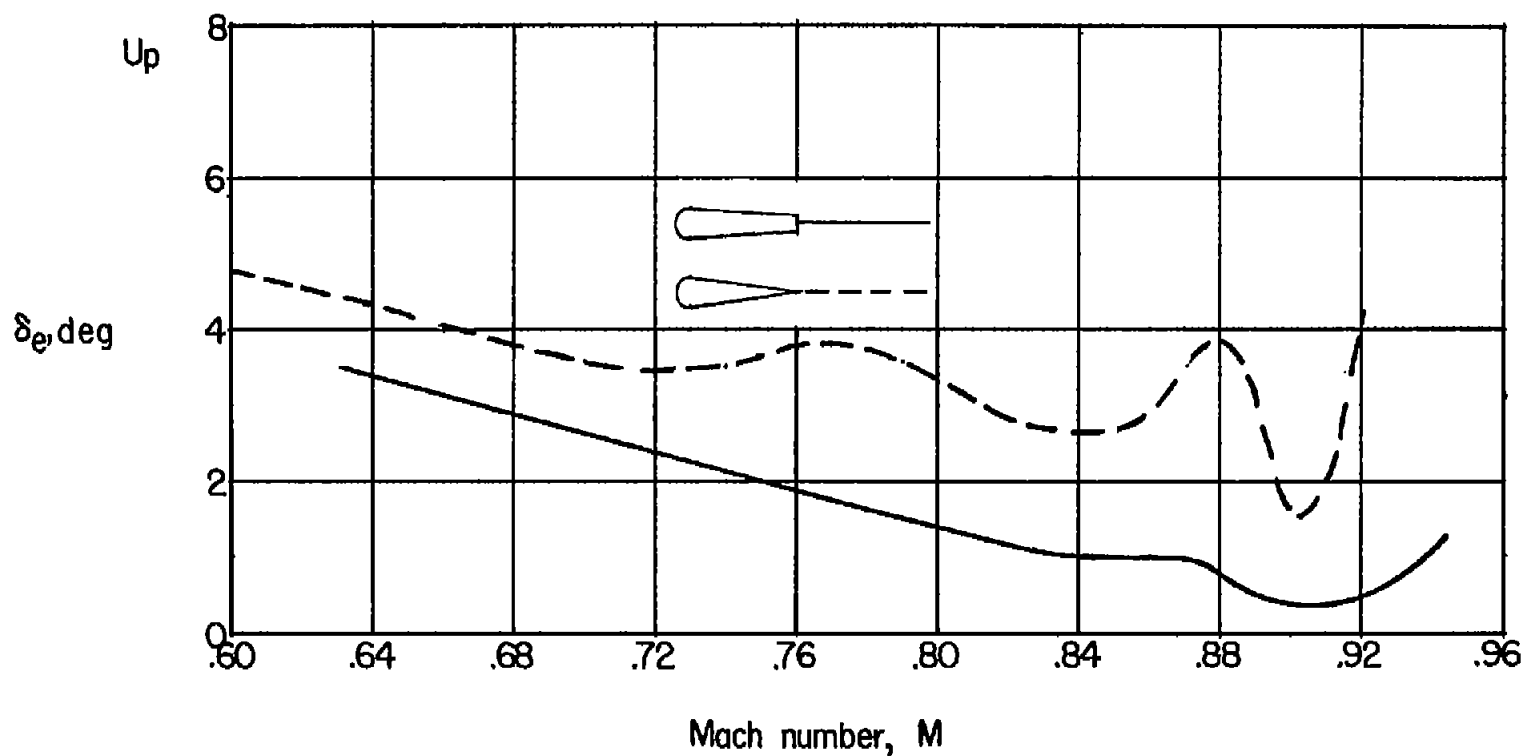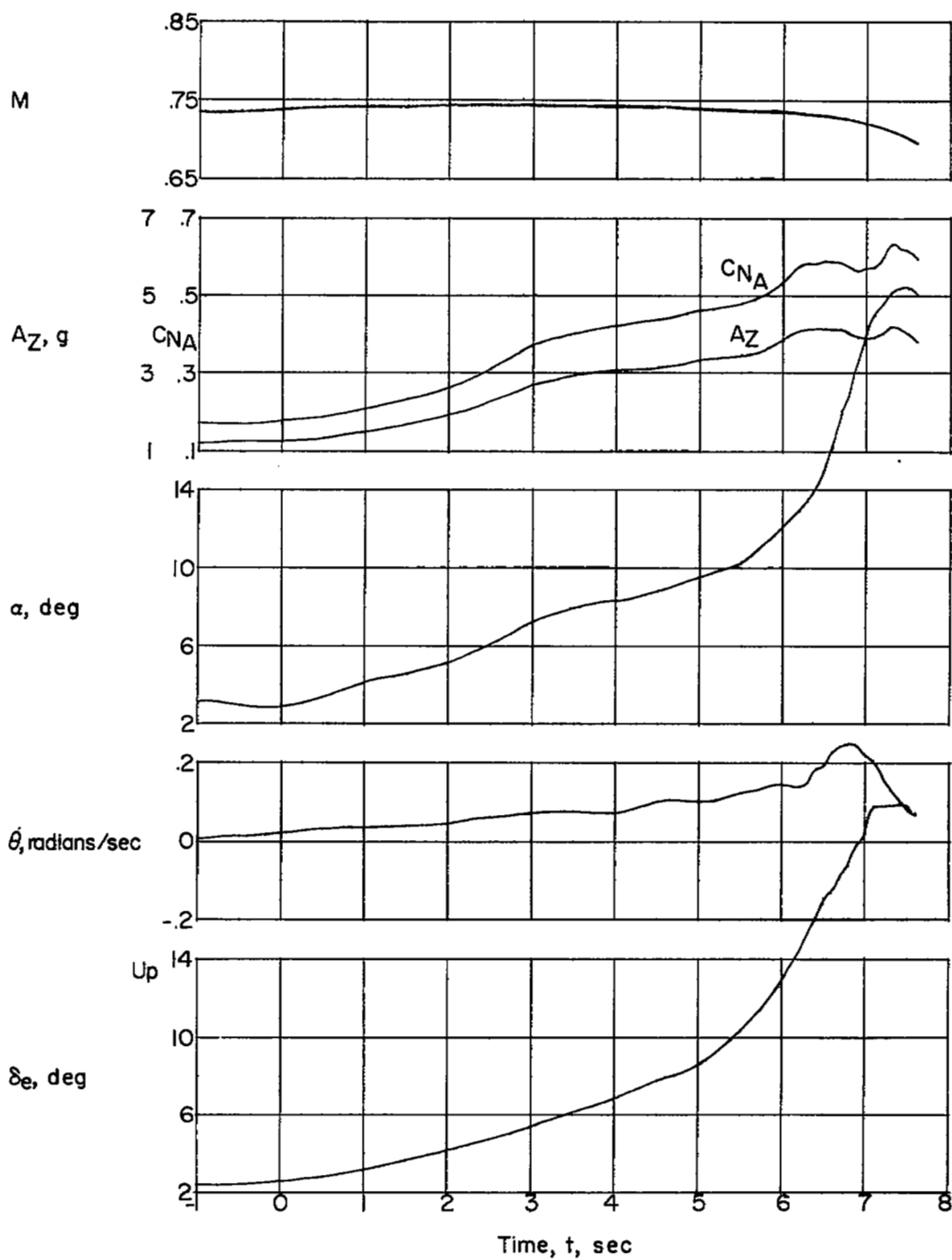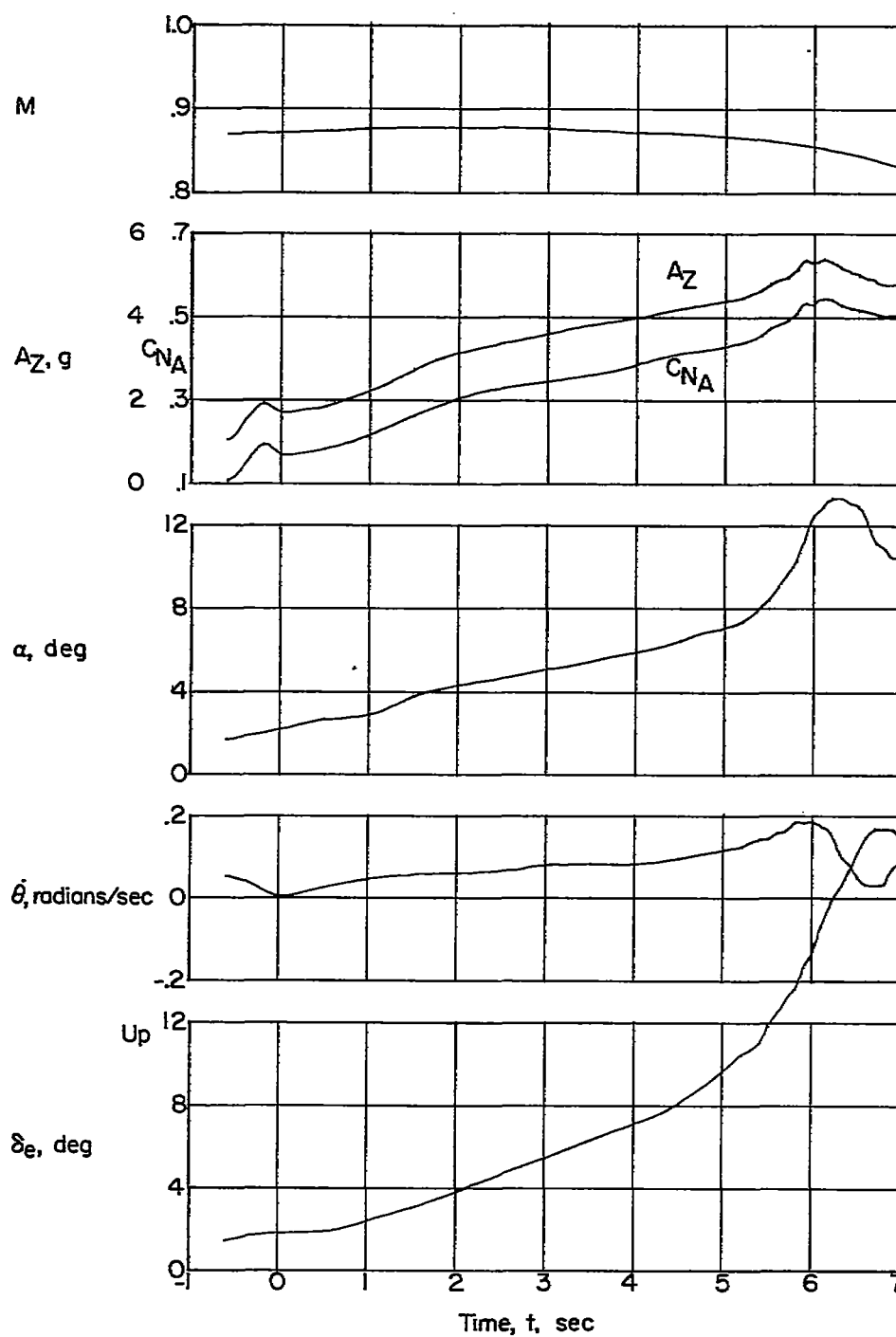Figure 4.- Profile of original and modified elevon. Trailing-edge angle of original elevon ≈ 19°; trailing-edge angle of modified elevon ≈ 8°. h ≈ 5.5 percent chord.

Figure 5.- Variation with Mach number of the longitudinal control deflection required for trim in level flight. $h_p \approx 30,000$ feet; c.g. at 17 to 18 percent M.A.C.

(a) $h_p \approx 29,000$ feet.

Figure 6.- Time histories of wind-up turns.

(b) $h_p \approx 28,000$ feet.

Figure 6.- Continued.
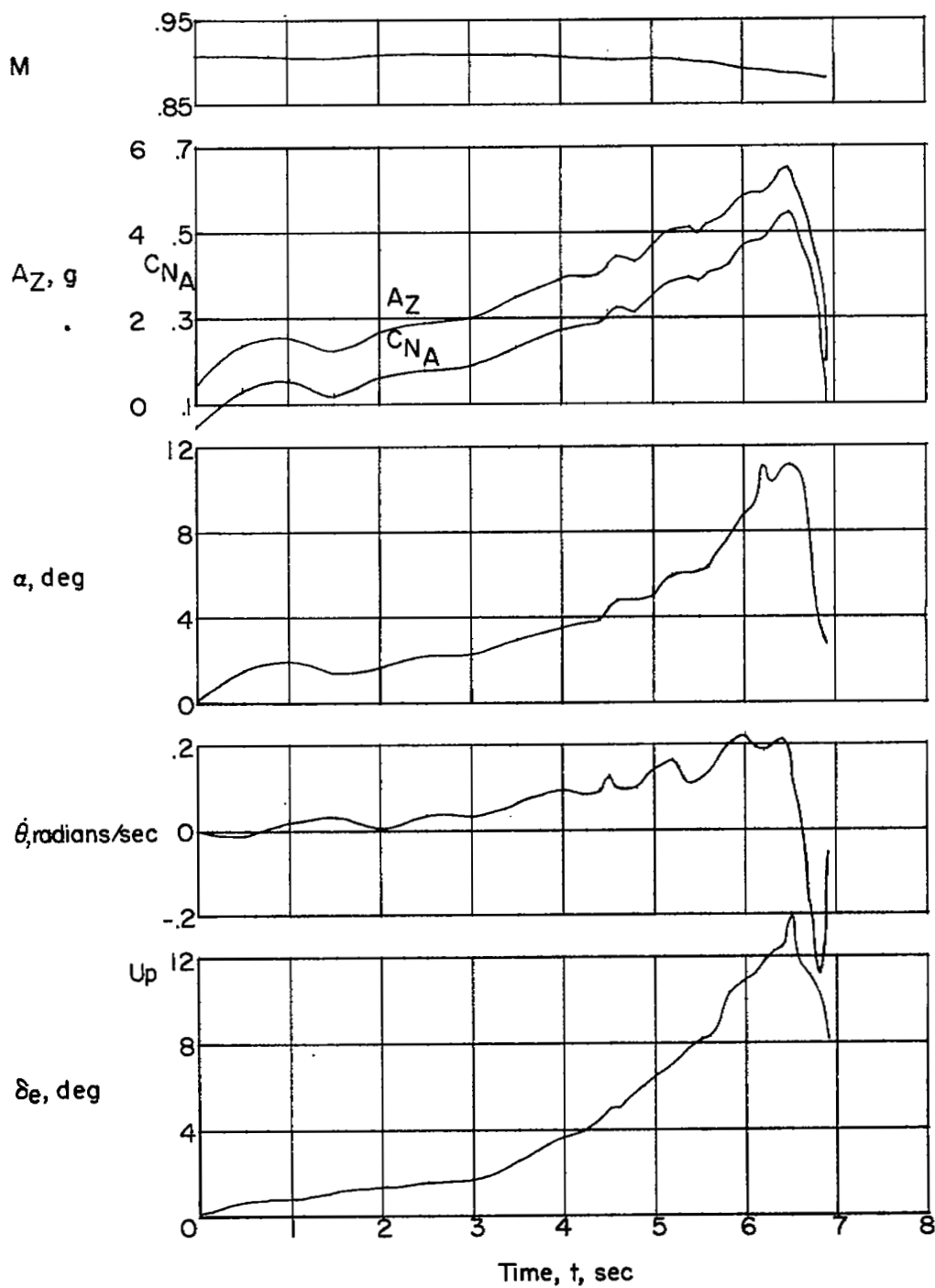
(c) $h_p \approx 29{,}000$ feet.

Figure 6.- Concluded.
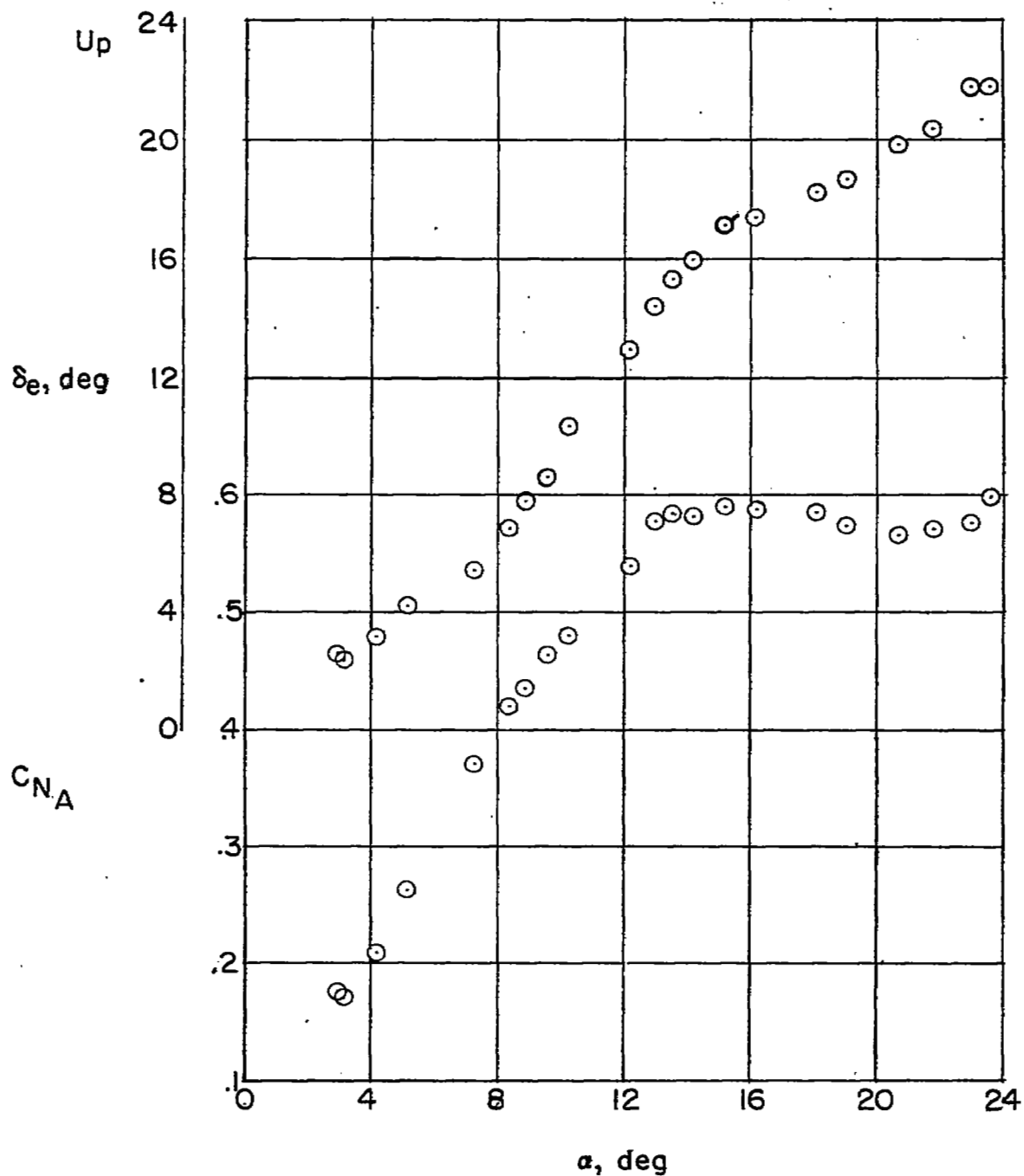
(a) M ≈ 0.73; h_p ≈ 28,000 feet.

Figure 7.— The variation of normal-force coefficient and longitudinal
control angle with angle of attack obtained in wind-up turns.

(b) $M \approx 0.86$; $h_p \approx 28,000$ feet.

Figure 7.- Continued.
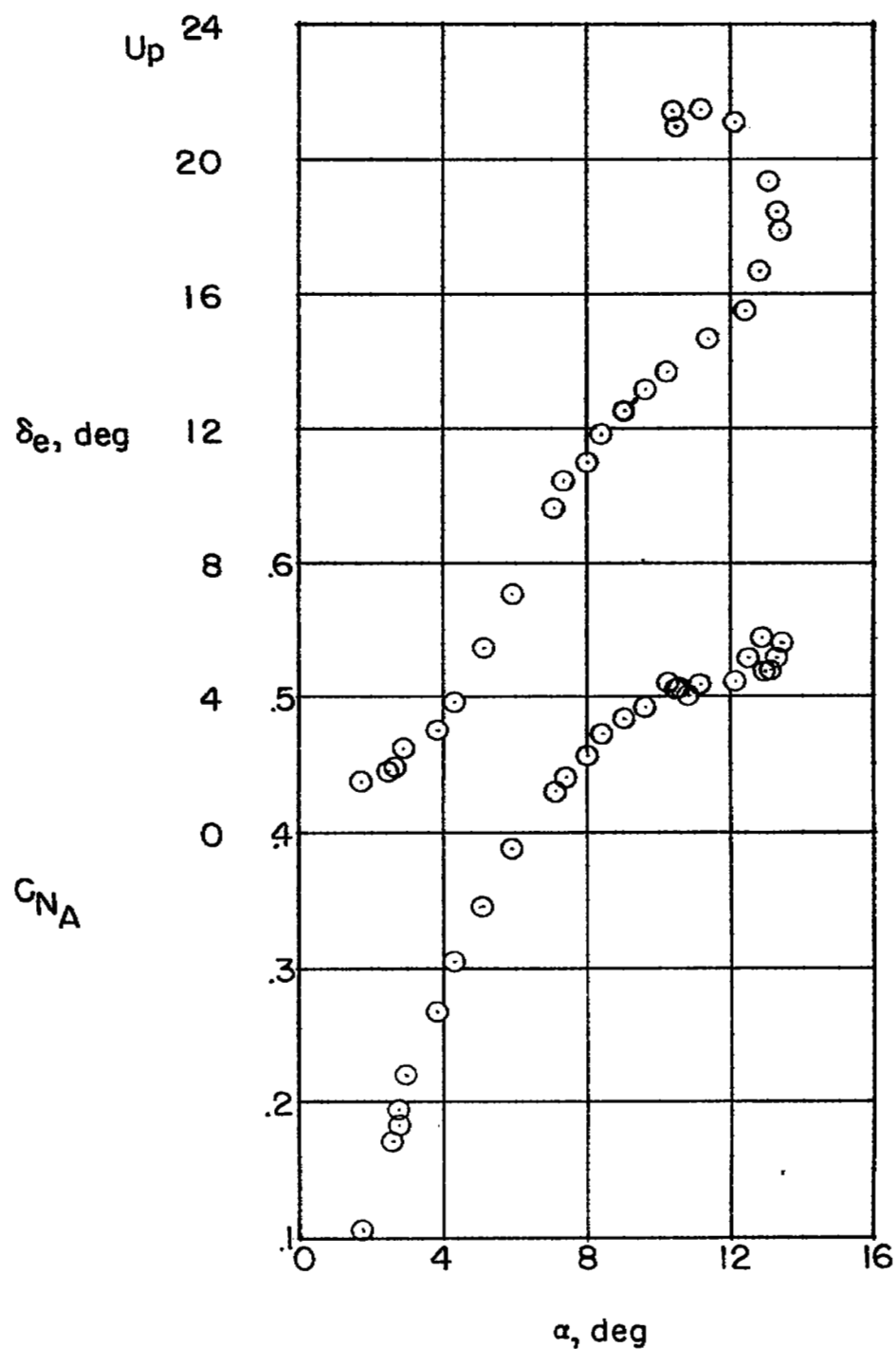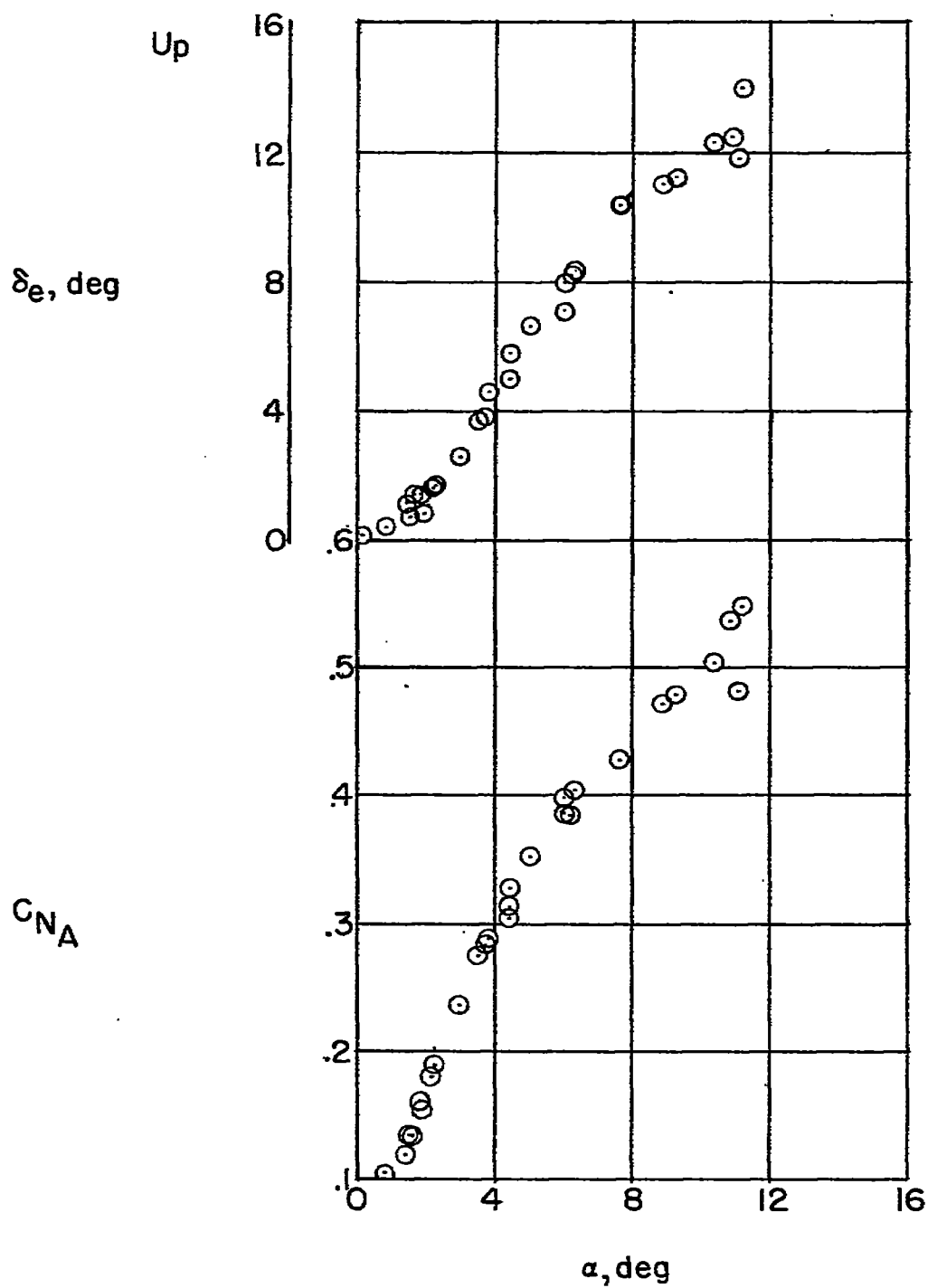
(c) $M \approx 0.90$; $h_p \approx 29,000$ feet.

Figure 7.- Concluded.
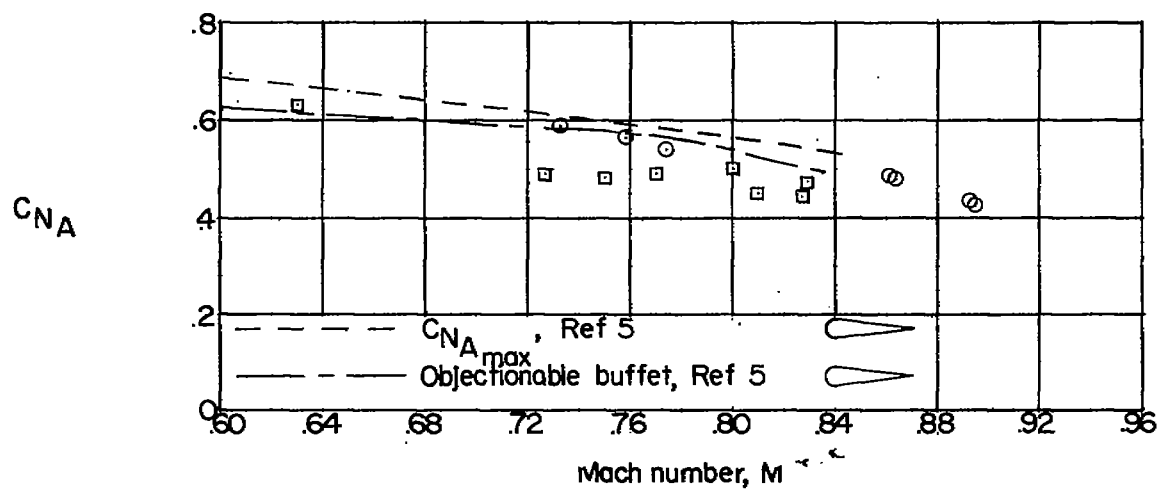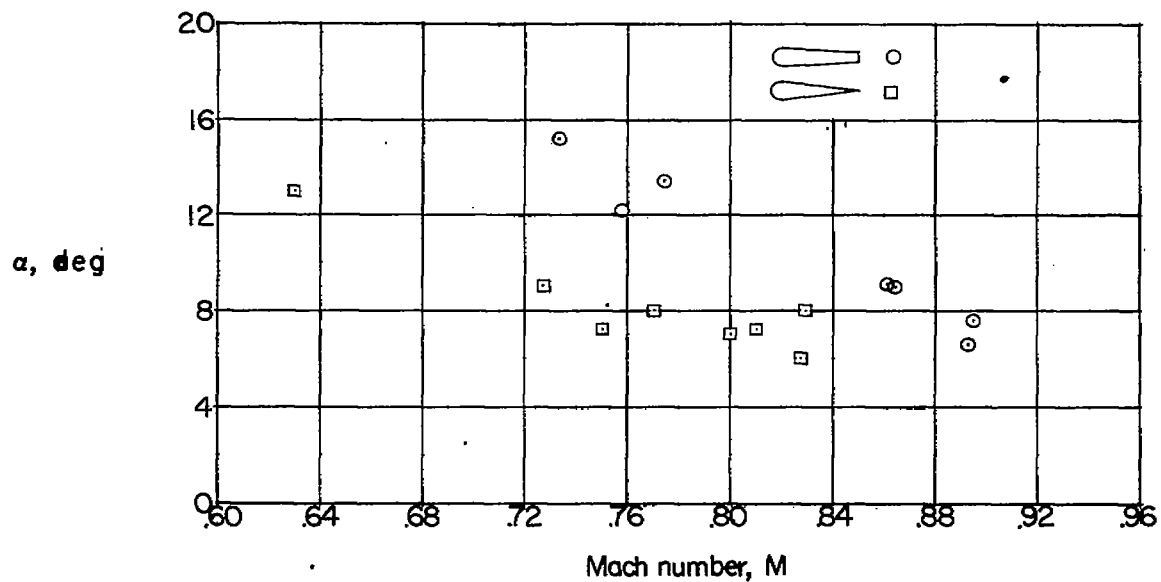
Figure 8.- Boundary describing decay of static longitudinal stability.
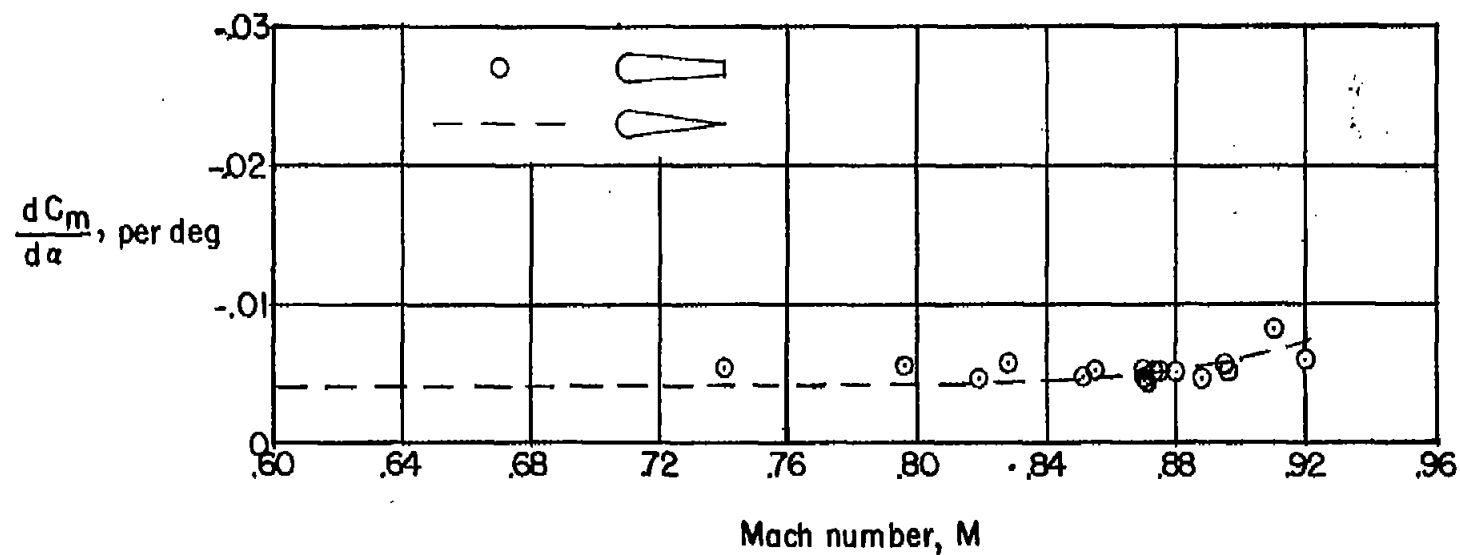
Figure 9.- The variation of static longitudinal stability with Mach number near level flight. $h_p \approx 30,000$ feet.
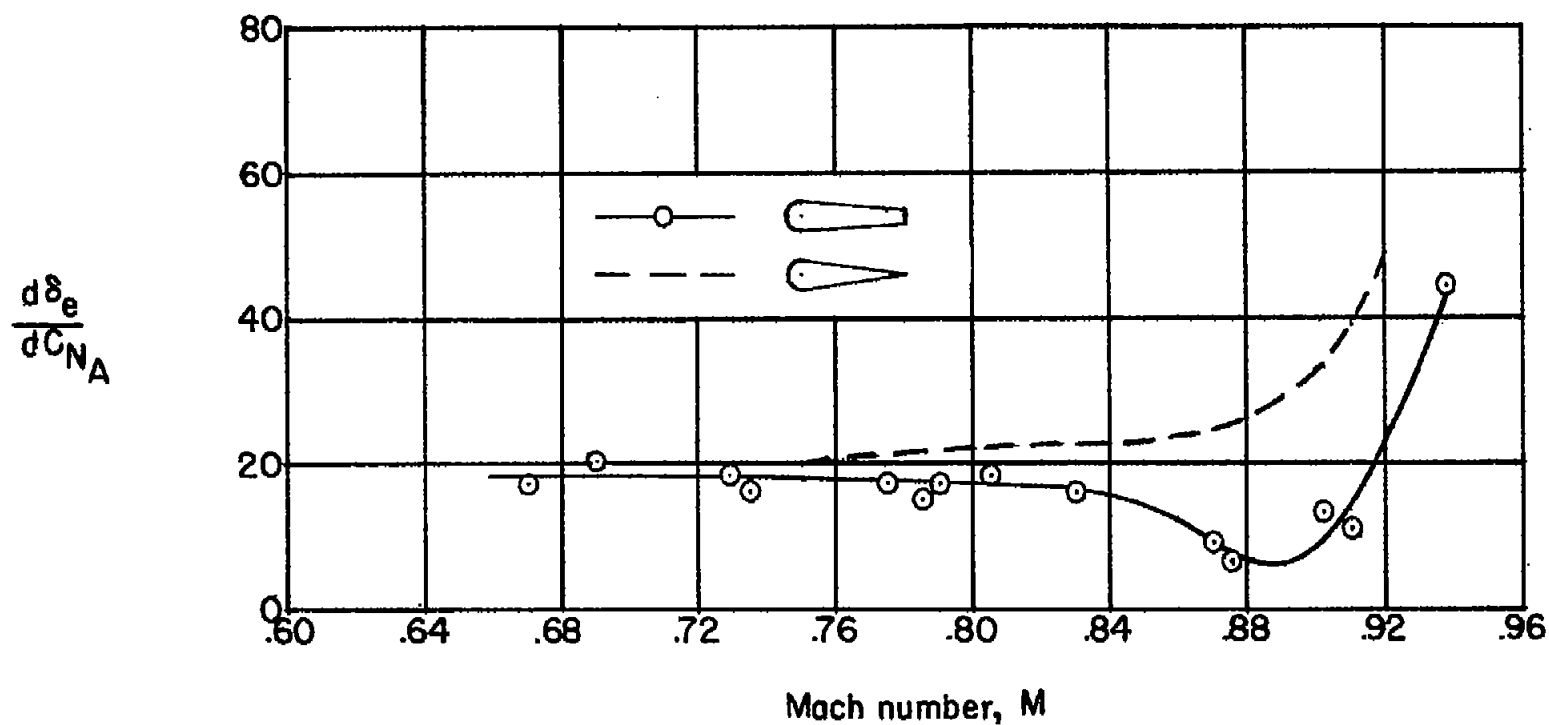
Figure 10.- The variation of the apparent static longitudinal stability parameter $d\delta_e/dC_{N_A}$ with Mach number near level flight. $h_p \approx 30,000$ feet.
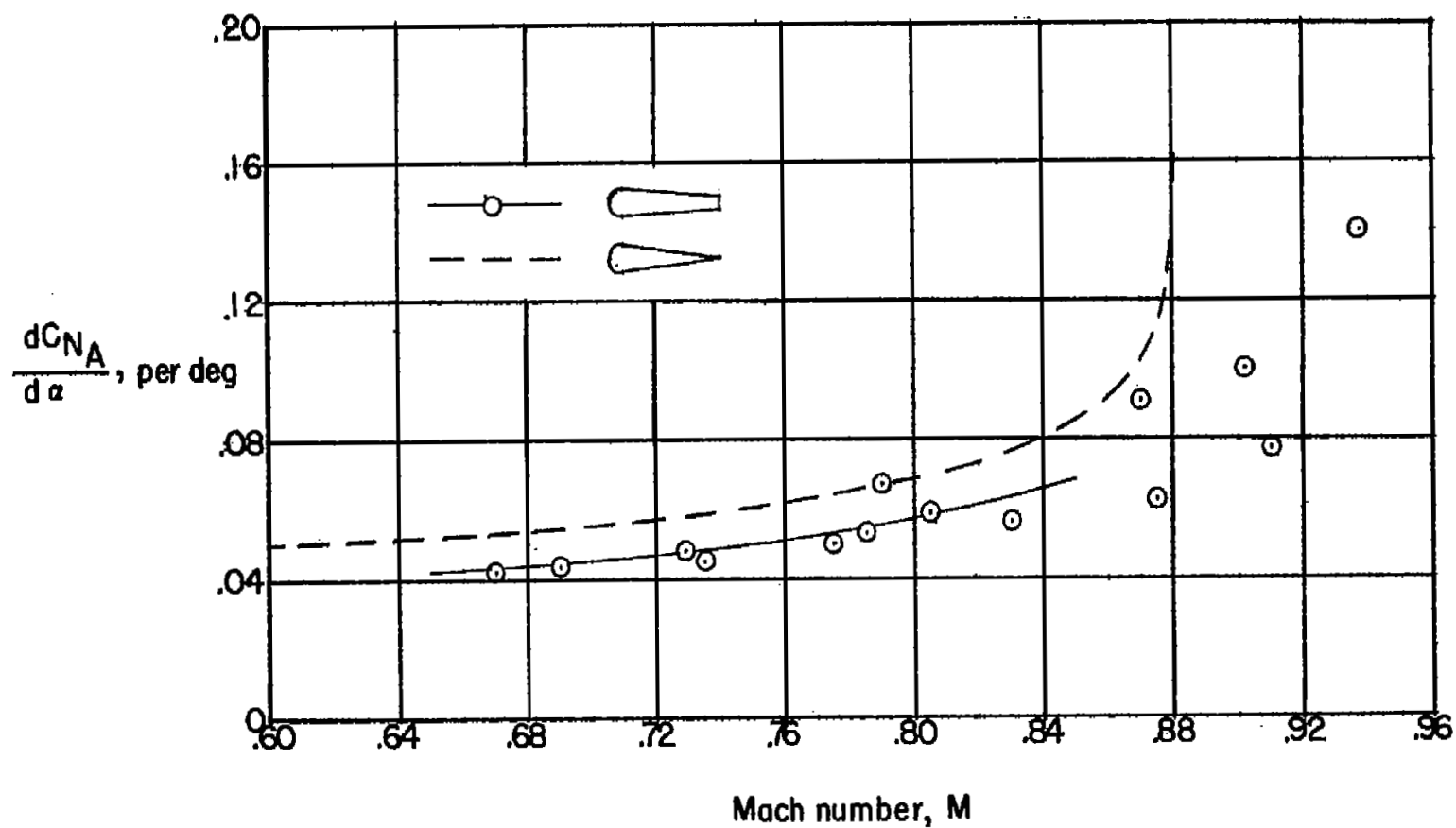
Figure 11.- The variation of normal-force-coefficient slope with Mach number near level flight. $h_p \approx 30,000$ feet.
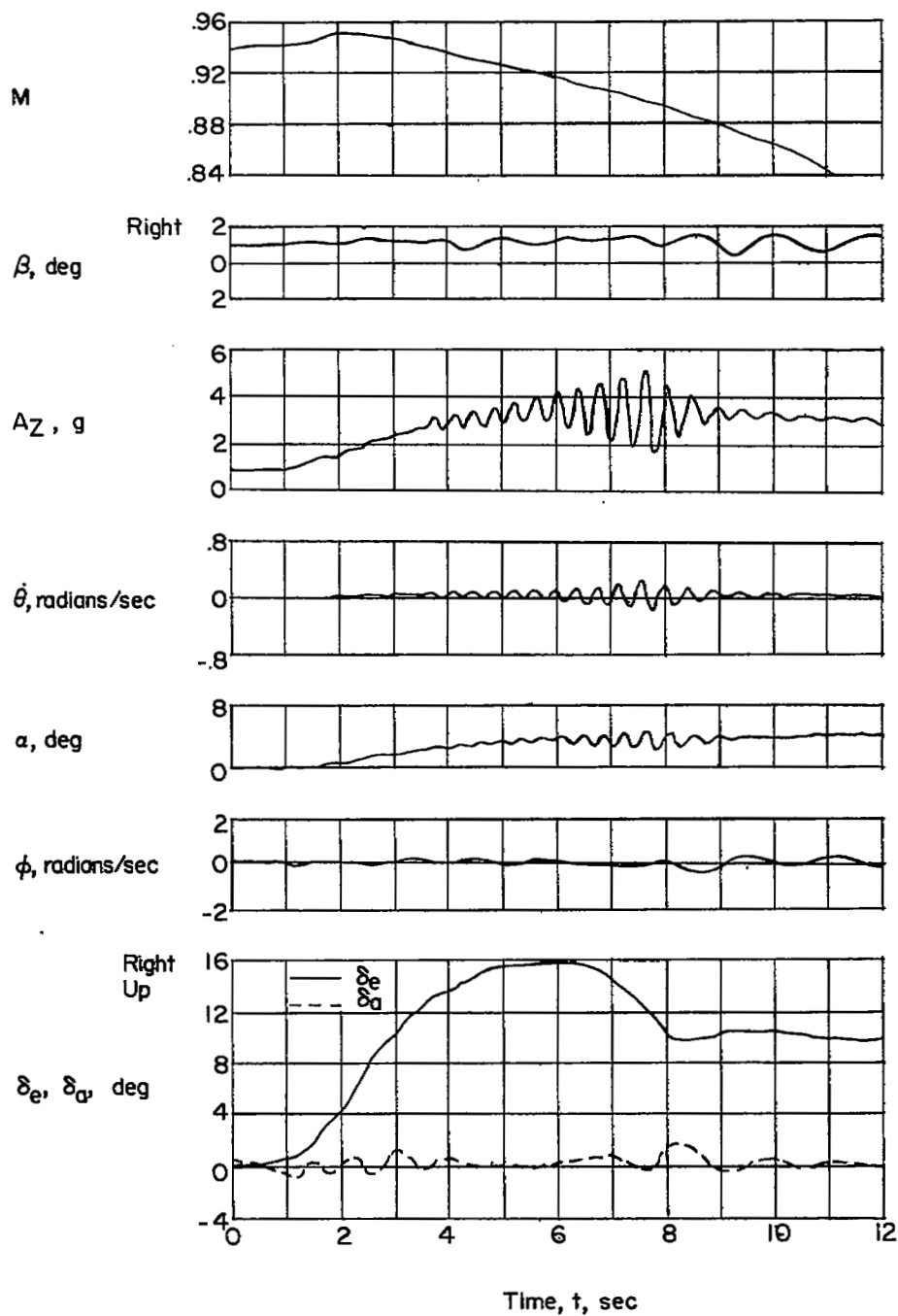
(a) Airplane induced.

Figure 12.– Time history of high amplitude, high frequency longitudinal oscillation. $h_p \approx 30,000$ feet, thickened elevons.
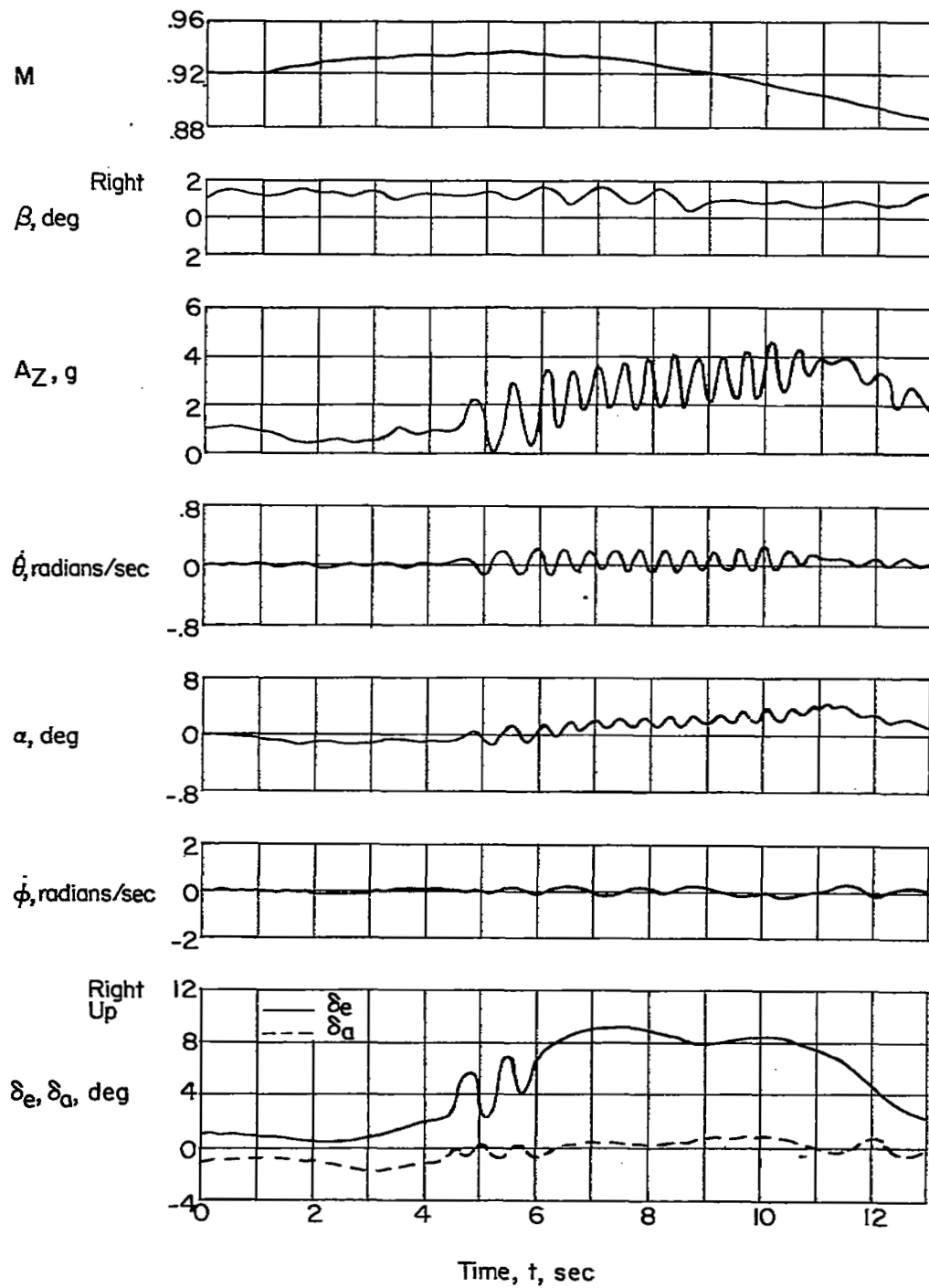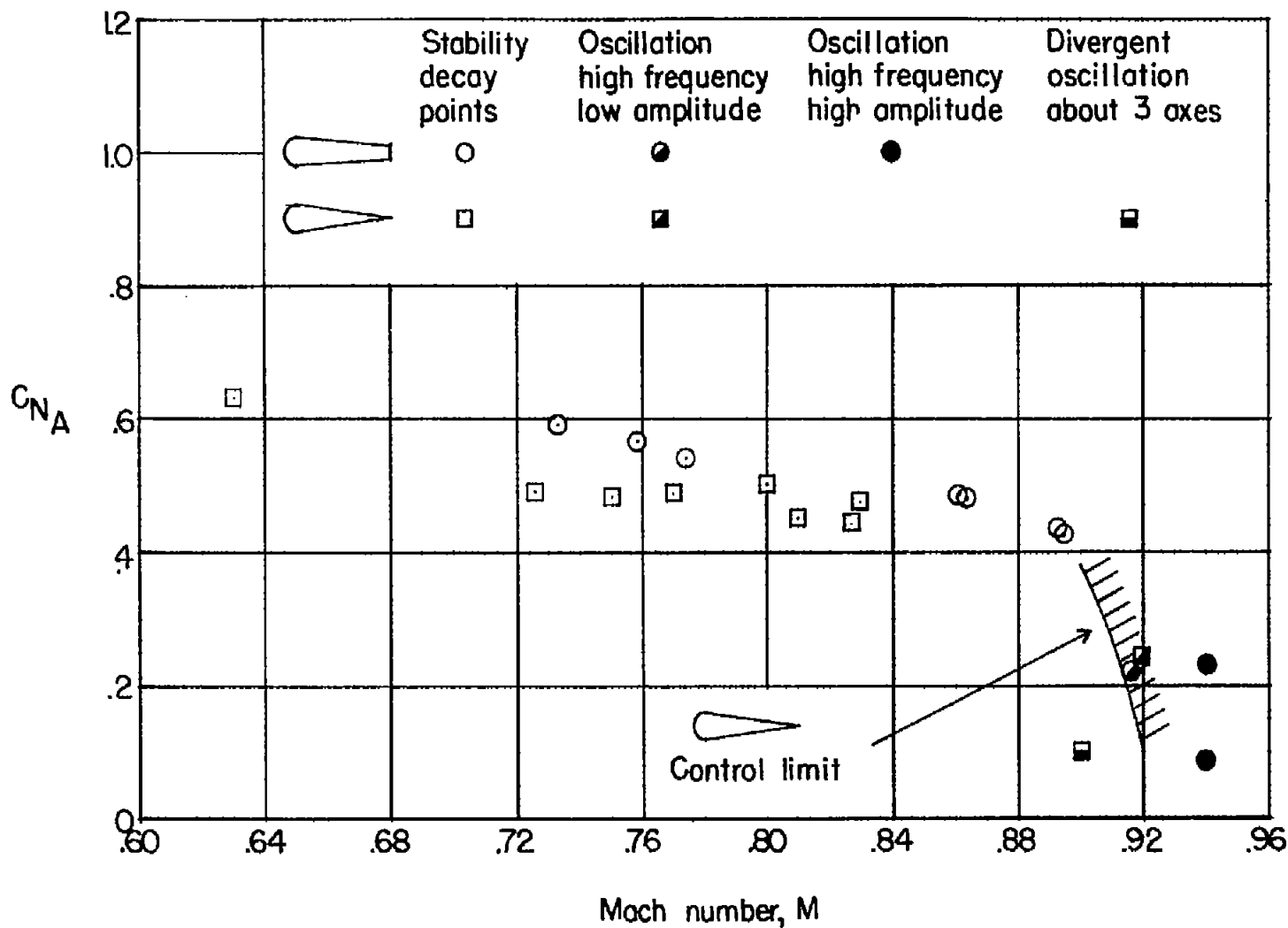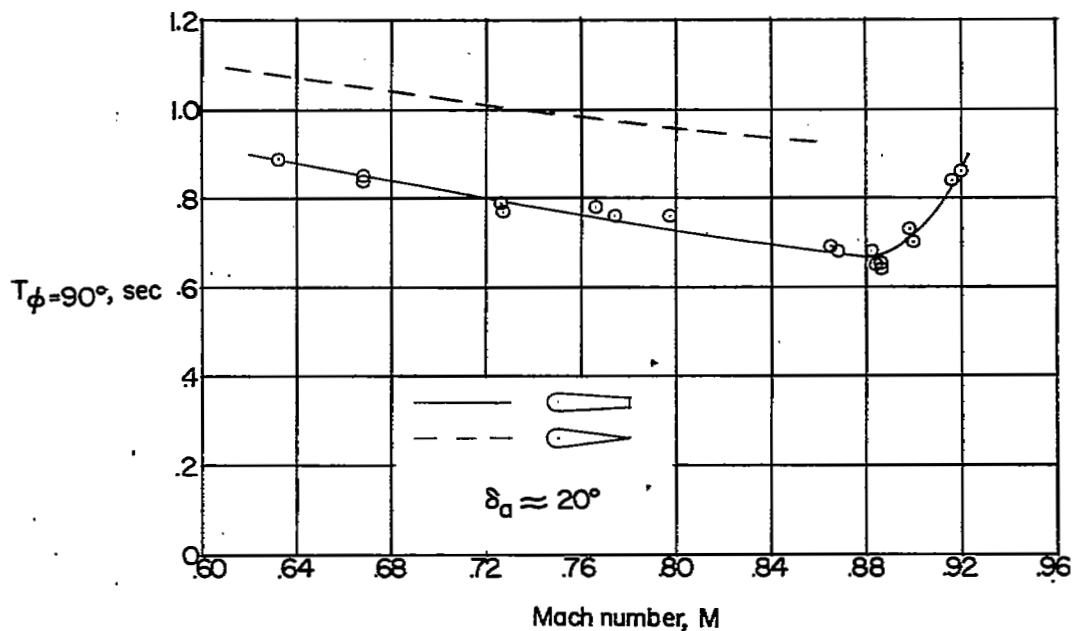
(b) Pilot induced.
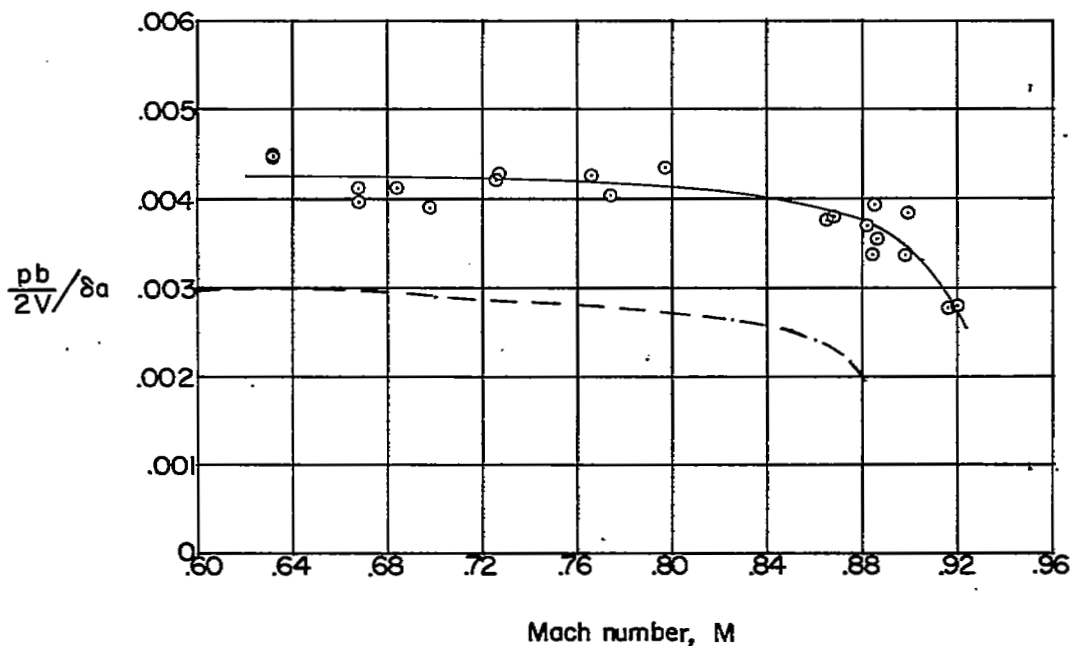
Figure 12.- Concluded.

Figure 13.- Usable flight envelope for the X-4 airplane.

(a) Time to bank 90°.

(b) Wing-tip helix angle per degree control deflection.

Figure 14.- Variation with Mach number of time to bank 90° and wing-tip helix angle per degree control deflection. $h_p \approx 30,000$ feet.